APPENDIX G

The Southern California Seismographic Network

EGILL HAUKSSON
California Institute of Technology
and
THOMAS HEATON
U.S. Geological Survey
Pasadena, California

Summary

The Southern California Seismographic Network (SCSN) is jointly operated by the Pasadena Office of the U.S. Geological Survey and the Seismological Laboratory of the California Institute of Technology. The SCSN has 224 remote sites (with 343 components) and gathers data from local, regional and teleseismic earthquakes. These data are used for earthquake hazards reduction as well as for basic scientific research. The earthquake hazards reduction effort has become more important as moderate-sized earthquakes continue to occur within densely populated areas in southern California. Although the USGS operates most of the remote stations in the SCSN, Caltech operates 24 short-period telemetered stations and 15 very broad-band TERRAscope stations. In 1994–1995 we plan to install four more TERRAscope stations. Caltech also maintains drum recorders and other equipment at the central site located in the Seismological Laboratory at Caltech.

The southern California earthquake catalog is prepared by Caltech data analysts under the supervision of Dr. Kate Hutton. More than 10,000 earthquakes were entered into the catalog every year from 1980–1991. Since 1992 an average of 30,000 events per year have been entered into the catalog. Approximately 3.0–5.0 Mbytes of phase data and 30–50 Gbytes of seismograms are archived every year. In addition, USGS personnel participate in the data analysis, software maintenance, hardware maintenance, and other tasks necessary to complete the catalog.

Near real-time reporting to USGS in Reston, FEMA, and the Governor's Office of Emergency Services and other response to any felt or damaging earthquake activity is shared by Caltech and USGS personnel.

The Data Center of the Southern California Earthquake Center (SCEC_DC). The SCEC_DC that is located in the Seismological Laboratory at Caltech was established to facilitate access and distribution of earth science data relevant to earthquake hazards reduction efforts in southern California. This data center has significantly increased the use of the data from SCSN for scientific research. The mass-store system, which became operational on 1 October 1991, provides on-line storage for more than 600 Gbytes of data that are all available via Internet. Jointly the SCSN and SCEC_DC maintain a data base that includes 1) earthquake catalog (1932–present), 2) phase data

(1932–present), 3) photographic paper seismograms (1930–1992), and 4) digital seismograms (1977–present).

Because of limited funding in the past, some data gaps exist in the SCSN data base. The SCEC has provided funds for one data analyst to analyze data and to help close these data gaps. The total effort is estimated to be 6–8 years for one data analyst. This data analyst started working when the Landers sequence happened and has helped with backlogs of data created by the Landers and Northridge sequences, but not the old backlog.

SCEC has also funded the entry of the phase data from 1930–1960 into a digital format. These data are being processed by K. Hutton and are available in preliminary form via the SCEC_DC.

TERRAscope. This project is a Caltech initiative, funded by private foundations, to upgrade the seismograph instrumentation in southern California to IRIS and USNSN standards. The L.K. Whittier Foundation of South Pasadena and the ARCO Foundation have already donated funds to pay for 19 permanent broad-band, high dynamic range stations and two portable broad-band PASSCAL type stations. In addition, the USGS has installed two new broad-band stations in San Bernardino, near the San Andreas fault, and a station on Superstition Mountain. The data from the broad-band stations are available from an on-line data archive at Caltech via the SCEC_DC and from the IRIS/DMS.

TERRAscope data from seven stations are received real-time at the Seismo Lab and used for automatic magnitude determination and testing of new real-time data analysis methods. The stations ISA and SMT are transmitted via the USNSN satellite system. Our future plans include merging the TERRAscope data with the data from SCSN on a routine basis for real-time analysis and for preparing the earthquake catalog.

Future SCSN. It is our goal for the year 2000 to evolve the SCSN into a modern reliable earthquake monitoring network capable of providing real-time information and on-scale high fidelity ground motion data. This ambitious goal has in part evolved from our experience with the 1992 M_w 7.3 Landers and the 1994 M_w 6.7 Northridge earthquakes. As the local governments, the private sector, and the public become more aware of the earthquake problem there is an increased need for accurate information. If reliable real-time earthquake information is available, it can be used by many segments of society to protect life and property. Similarly, there is a dual need for rapid, accurate evaluation of strong ground shaking. First, maps of strong ground shaking are needed to guide emergency operations immediately following a major earthquake. Second, strong ground shaking that in most cases causes over 95% of the earthquake damage needs to be mapped to facilitate our understanding of damage and subsequent improvements of building codes.

Introduction

The objectives of the SCSN continue to evolve with the high rate of earthquake activity in southern California. The present and future objectives of SCSN involve 1) providing reliable near-real-time earthquake information to save lifes and protect property, 2) collecting high fidelity data for ground motion and earthquake source research, and 3) collecting earthquake data for earthquake statistical, seismotectonic and tomographic research.

The strategies needed to accomplish these new objectives consist of 1) new digital instrumentation, 2) digital data transmission, 3) new processing hardware and software; 4) new approaches to real-time notification to remote users, 5) changes in emphasis for routine analysis of data, and 6) new management structure for the network. To meet these new objectives the next 3 years will be a rapid time of change for the SCSN.

The area monitored by the SCSN includes two of the ten largest cities in the United States (Los Angeles and San Diego) and almost 20 million inhabitants. More than one hundred earthquakes (not including aftershocks) are felt each year and an average of 1.5 events per year are potentially damaging (magnitude greater than 5.0) (Fig. 1). The need for information about these earthquakes is great. Immediately after a moderate or large earthquake, information about the size, location and damage from the event is needed to coordinate rescue operations, guide inspectors in the search for damage, and to satisfy public curiosity. The record of earthquake occurrence in California is important to insurers, geotechnical engineers, and city planners. The SCSN has maintained and published a catalog of earthquakes above magnitude 3.0 since 1932 and above magnitude 2.0 since 1980 with consistent magnitudes over the whole time.

Although reliable prediction of the time, place and magnitude of impending earthquakes is not yet possible, scientists can recognize times of increased hazard of damaging earthquakes, for instance after a potential foreshock or during an aftershock sequence. Recent advances have made it possible in some situations to estimate the probability that an event will be followed by a larger earthquake (e.g., Jones, 1985; Agnew and Jones, 1991) and the probabilities of damaging aftershocks (Reasenberg and Jones, 1989). One of the purposes of the Southern California Seismographic Network is to provide the data necessary to make these evaluations. The earthquake data recorded in southern California are processed in near-real time, and if appropriate, probabilities of future earthquakes are calculated. These probabilities and other requested advice are provided to USGS Reston, FEMA, and the State of California and through the Governor's Office of Emergency Services (OES) to the public.

An additional purpose of the Southern California Seismograph Network is to provide data for research in seismology, earthquake physics and prediction, and tectonics. Southern California is the most seismically active region in the contiguous United States and provides a unique seismotectonic environment of moderate convergence along a transform plate boundary. The large numbers of earthquakes (more than 200,000 earthquakes) and the long history of the catalog make this data set an important resource for studies in seismology and earthquake physics. The earthquake data also can provide important constraints in the analysis of the geology of southern California.

We have begun and expect to continue the process of upgrading the network to meet the demands of modern seismology. With the new techniques available for analyzing the waveforms

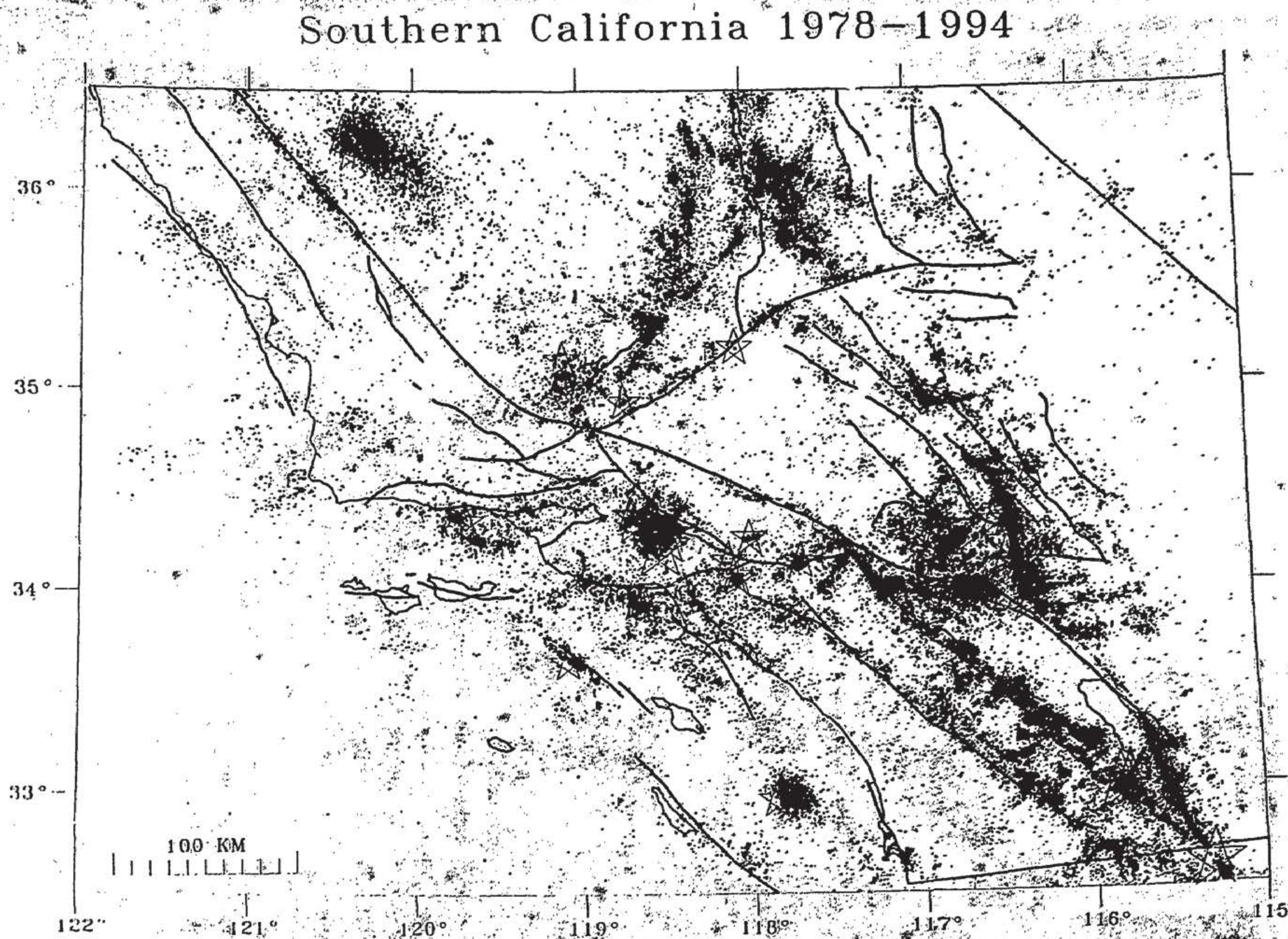

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Fig. 1. Seismicity of southern California 1978–1994.

42

of local earthquakes, the quality, bandwidth and dynamic range of the seismic signals have become much more important. Already 17 (15 Caltech stations and two USGS stations) digital, broad-band, high-dynamic range seismic stations with Streckeisen seismometers have been installed. At least four additional broad-band stations will be installed in 1994–1995. We will also continue to improve the quality of the existing short-period network. The on-scale, calibrated waveforms needed for research also could form the basis of an early warning or SCAN (Seismic Computerized Alert Network) system. Such a system would automatically analyze incoming seismic signals to determine within a few seconds if a large earthquake was starting and, if so, the epicenter and probable magnitude. We expect the network to evolve and in the future to provide an early warning of large earthquakes to the people of southern California.

Several fund-raising efforts are in progress to raise funds for the capital improvement of the SCSN in the wake of the Northridge earthquake. If these efforts are successful, the operation and development of the SCSN may take a quantum leap forward in the next 3 years. If no significant new funds become available, the SCSN operation will evolve at a very slow pace.

Network Operation

The Caltech network operation consists of 1) operating computer hardware/software and other instrumentation for data acquisition at the central site, 2) field maintenance of remote short-period telemetered instruments, and 3) installation and field maintenance of TERRAscope stations and other new digital instruments.

Central Site

The SCSN data are acquired by two microVAX-III computers and the data processing is done on six VAX workstations using a VAX-4000 as a central server. The installation and operation of this equipment that was last upgraded in 1990–1991 is shared by Caltech and USGS personnel.

Data channels arriving at the central recording site at Caltech are demodulated back to analog signals, passed through anti-alias filters at 20 Hz and then converted to 12-bit digital data (±2048 counts) at 100 samples per second by two independent Tustin digitizers. Event detection, phase detection, and rapid location and magnitude determination is done on one of the microVAX-III on-line systems. Event files of time-series data are also saved for off-line processing in CUSP. To avoid duplication, software development for the on-line systems and CUSP is done in cooperation with the USGS in Menlo Park.

Backup is provided by continuous recording of the whole network onto Digital-Audio-Tapes (DAT). In addition to backup recording the DAT-tapes are ideal for recording teleseisms. The DAT-tapes are saved if a significant teleseism has occurred or there are problems with the on-line routine recording. The SCSN is the first network to use this new technology for continuous recording of data.

Remote Stations

At present the SCSN records 343 channels of data from 224 sites (see Table 1). Most of the sites have a short-period (1-sec) vertical seismometer running at the highest gain permitted by the local noise levels. The station spacing is 15 to 30 km (Fig. 2) over an area of roughly 150,000 km^2. We have determined GPS locations for all of the stations. The data at some of the stations are augmented by other sensors. Ten three-component sites include an additional two horizontal seismometers. Ten sites have an additional vertical seismometer running at a lower magnification (typically 1/16 the magnification of the high-gain component). Eight sites have three-component Force Balance Accelerometers (FBA). Figure 3 shows the distribution of the sites that have these additional data channels. The analog data signals are amplified and modulated by Voltage Controlled Oscillators (VCO) at the station and then sent by various combinations of FM telemetry, phone lines and microwave links to the central recording site at Caltech.

Table 1. Stations and channels digitally recorded by the SCSN.

Agency Maintaining Stations	Number of Stations	Number of Components
USGS, Pasadena	172	279
Caltech	24	32
USGS, Menlo Park	8	8
USC	12	16
DWR	6	6
UCB	1	1
UNR	1	1
TOTAL	224	343

Over the last 5 years we have improved the quality of the waveforms recorded by the short-period instruments. Signal quality has been analyzed and the amplification has been decreased at more than 50 stations to improve dynamic range. We have searched for electronic noise and eliminated it whenever possible through repairing and replacing VCO's and discriminators and filtering out high frequency noise in the central recording facility. The average dynamic range of the high gain stations has improved from about 30 dB to 45 dB.

Current information about the configuration of each network station (sensor type, amplifier type, gain settings, etc.) is documented in an easily accessible PC database, which is updated within a few days of any modifications. The database has proved useful to technicians and scientists who wish to obtain detailed instrument information, for example, searching for all sites that have a particular type of electronic amplifier, or tracing the history of gain settings at a particular station. These database files can also be used in a computer program which removes the instrument response from the network waveform data to produce (band-limited) ground displacement or velocity seismograms.

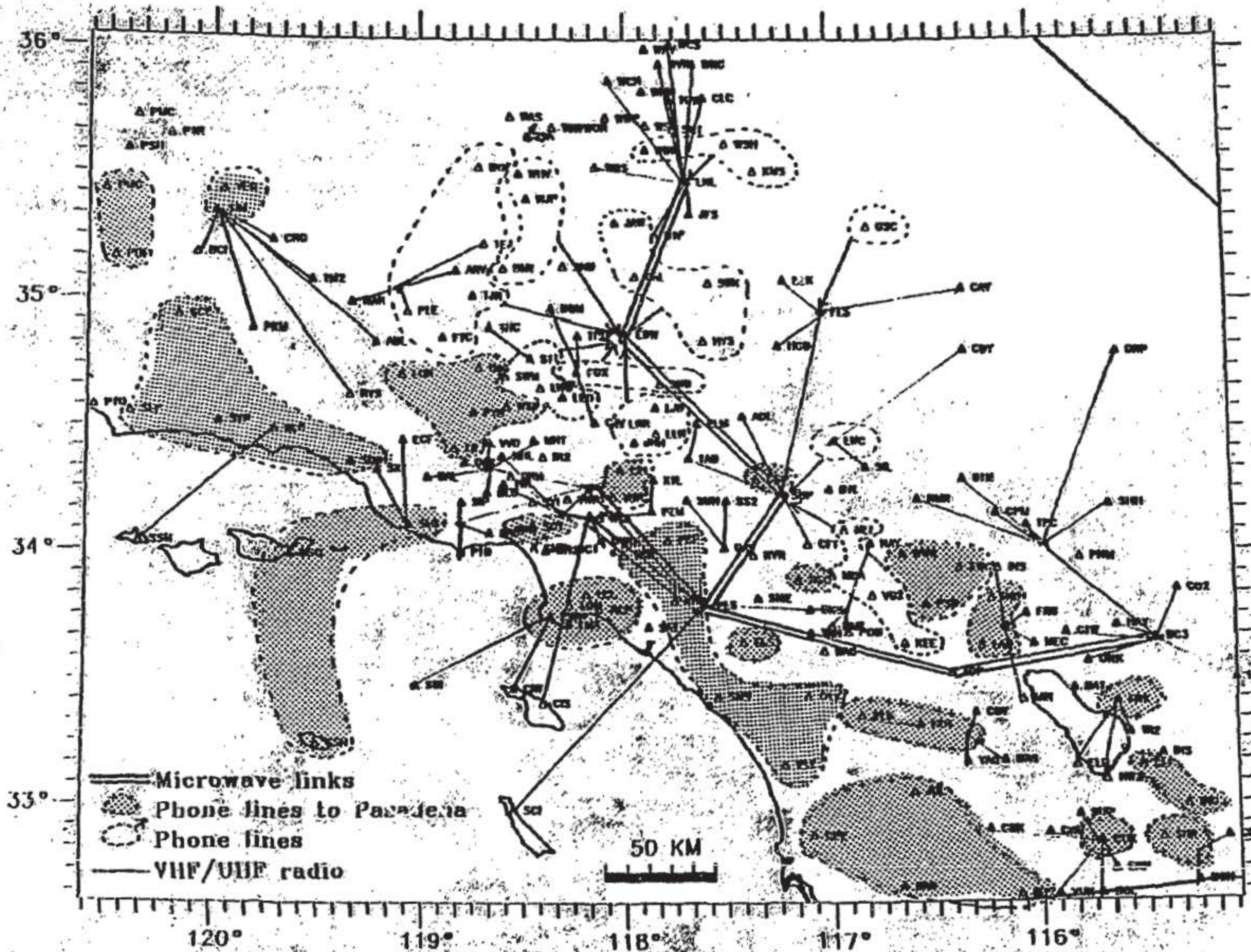

Fig. 2: The Southern California Seismographic Network; triangles indicate locations of stations. Data transmission links are also indicated.

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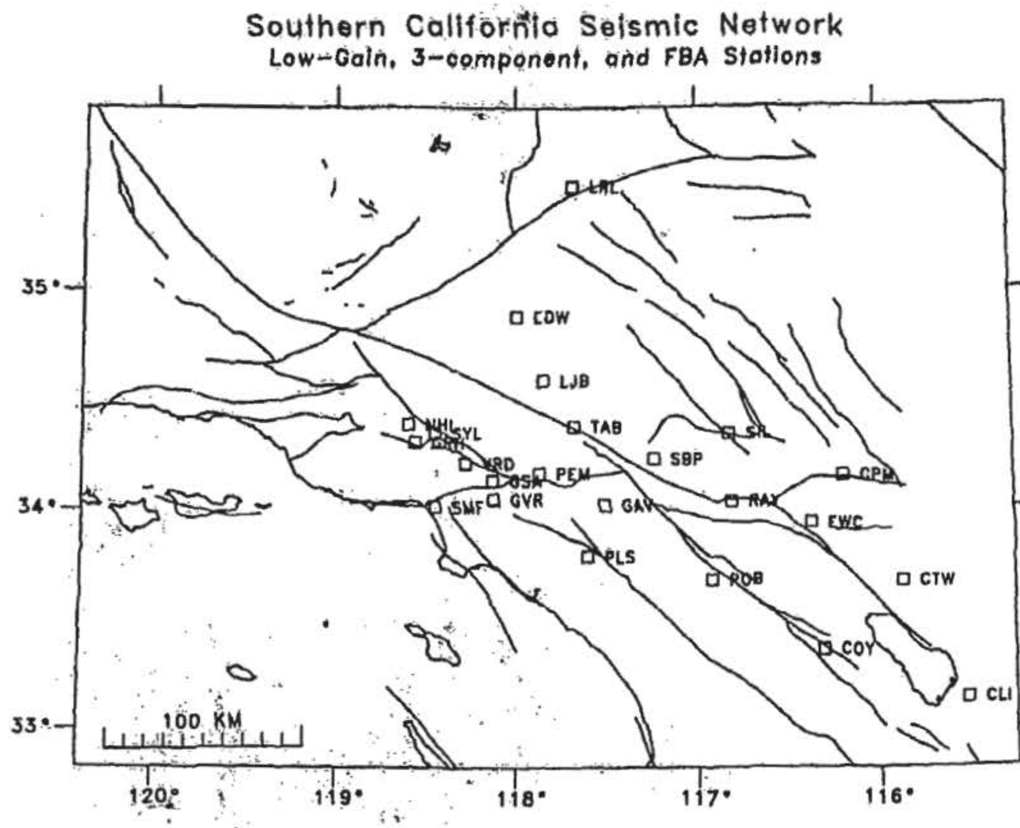

Fig. 3. Low-gain and high-gain seismometer, and ultra-low-gain Force Balanced accelerometers (FBA) stations in the Southern California Seismic Network.

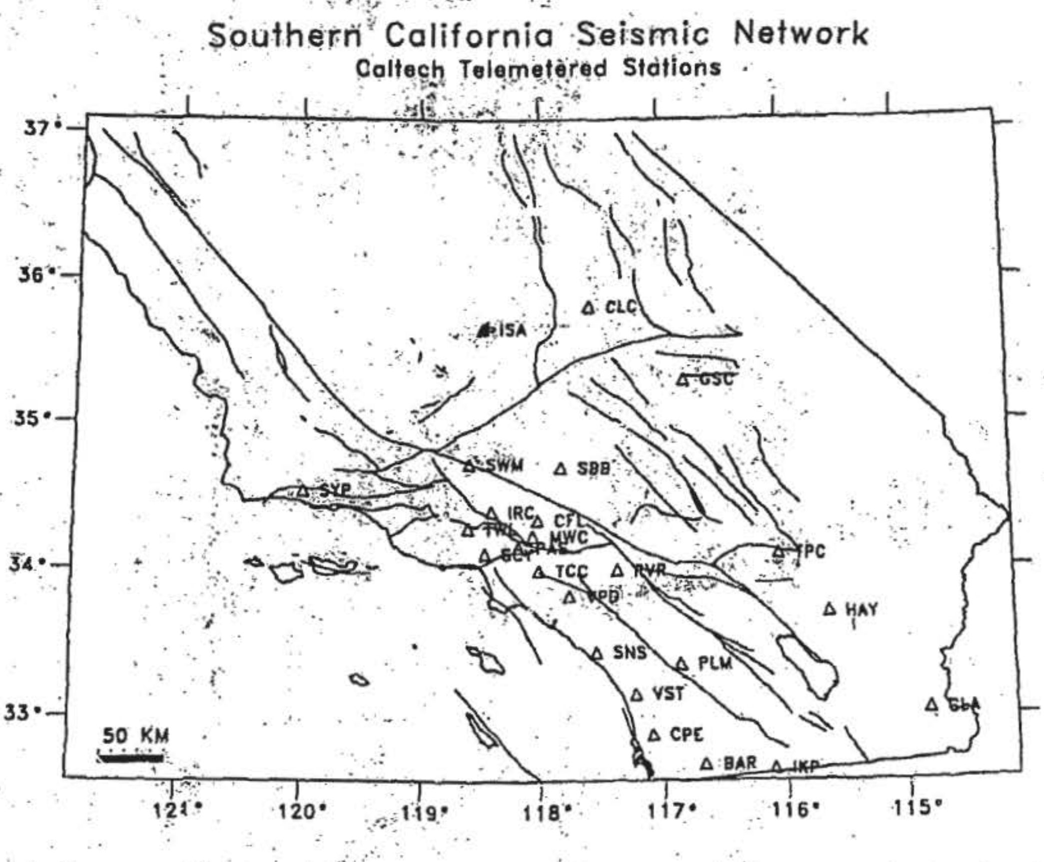

Fig. 4. Telemetered stations operated by Caltech. Triangles indicate locations of stations.

Caltech is responsible for field maintenance of 24 of the 224 remote telemetry stations (Fig. 4), while the USGS Office maintains 172 remote sites. Sixteen channels of data are received from USC, eight channels from the USGS in Menlo Park, and six channels from Department of Water Resources (Table 1).

In addition to the remote telemetered sites, Caltech used to operate seven stations with on-site photographic recording. Most of these stations were installed in the late 1920's. The instrumentation consisted of different combinations of Wood-Anderson seismometers, Benioff seismometers and Press-Ewing 1-90 seismometers. All photographic recording was terminated in late 1992 to early 1993. Some of these stations are now part of TERRAscope and have been upgraded with Streckeisen seismometers and Quanterra data loggers.

TERRAscope

In 1988, when Caltech received a grant from the L.K. Whittier Foundation, the development of TERRAscope began. The initial goals for TERRAscope were to install at least a dozen modern broad-band (10 Hz to DC) and wide dynamic range (nominally 200 db) seismographic stations with "real-time" data retrieval capability. Each station has a broad-band Streckeisen STS-1 or STS-2 seismometer and Quanterra data logger with a 24-bit digitizer and a Kinemetrics FBA-23 strong-motion sensor. As of July 1994, 17 TERRAscope stations are in operation (Fig. 5).

TERRAscope complements and extends the capabilities of the existing 224 station (343 components) short-period SCSN. The data from TERRAscope will also be included in the SCSN data base used for generating the CIT/USGS southern California earthquake catalog. Because of their real-time capability and location in a populous earthquake-prone area, both networks enable seismologists to provide the public, Federal, and State officials with timely information about significant earthquakes.

The TERRAscope stations are also included as a subnetwork of the global seismographic network, operated by IRIS, and of the USNSN, operated by the U.S. Geological Survey.

Analysis of the new high-quality data recorded at PAS from numerous regional earthquakes, including the December 1988 ($M_L = 5.0$) Pasadena earthquake at an epicentral distance of 3 km, have demonstrated that the high-quality broad-band data are the cornerstone needed for significant advances in both regional seismology and studies of teleseisms. In particular, the broad-band data recorded at 10 TERRAscope stations, from the 17 January 1994 (M_w 6.7) Northridge earthquake were easily available immediately after the event to determine the style of faulting and other seismological parameters of the earthquake. The very encouraging results of analyzing TERRAscope data so far have led us to modify the initial goal of a dozen stations to a goal of 21 stations in southern California.

Data Availability. TERRAscope data are recorded in both continuous and event-trigger modes on site. The tape cartridges that contain continuous data are sent to the IRIS/USGS Data Collection

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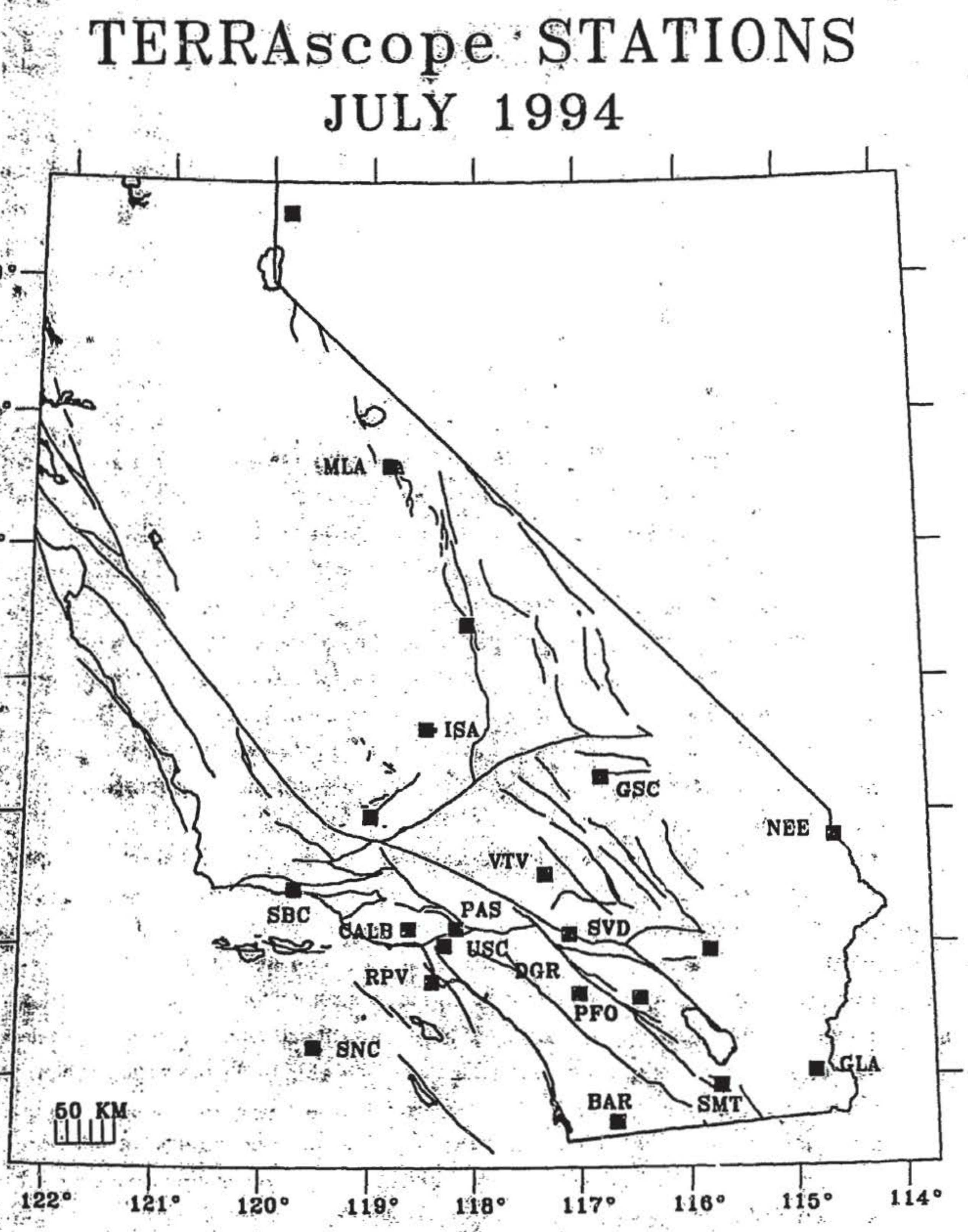


Fig. 5. TERRAscope stations. Squares labeled with three letter codes represent stations already in operation, squares that are not labeled represent stations to be installed in 1994–1995.

Center at Albuquerque and archived at the IRIS Data Management Center. These data are available upon request from the IRIS/DMC.

For quick and efficient data access, an automatic dial-up data retrieving system called Caltech Gopher (adapted from the IRIS Gopher system) has been implemented. The Caltech Gopher receives E-mail from NEIC for teleseisms and the SCSN with origin time, location, and magnitude for regional events. The Gopher retrieves data from 15 TERRAscope stations for these events. The data are available to users through the SCEC_DC. Usually the data are available within 30 minutes after the occurrence of a local or regional event and several hours after the occurrence of a teleseism.

Future Developments. With funds provided by the L.K. Whittier Foundation and ARCO Foundation we plan to deploy four more stations during 1994–1995. Although the actual locations have not been finalized, the following sites are being evaluated: Eastern Mojave, Owens Valley, Coast Ranges, and Reno, Nevada (Fig. 5).

To have the data available for immediate analysis following a major event we are testing two real-time telemetry systems. One is a satellite telemetry system that was installed in cooperation with the USNSN. This has made one TERRAscope station, ISA, a part of the USNSN. The other is based on data transmission over digital telephone lines (ADN) and a local real-time data collection system developed by our senior computer programmer. Because the ADN leased lines are expensive, we plan to start using Frame-Relay, which are virtual dedicated leased lines, as a way of transmitting the TERRAscope data real time. Frame-Relay is more cost effective than ADN because no distance or usage charges are involved.

Catalog Preparation and Data Access

The catalog preparation done by the SCSN staff consists of 1) demultiplexing and removal of noise events, 2) picking of P and S phases and locating the events, 3) magnitude determination, 4) completeness check, and 5) archiving of the data. In addition, the staff involved with production of the catalog responds to earthquake crises, request for information about earthquakes, and assists data users with data access.

Data Products and Access

With over 30,000 earthquakes recorded per year, the SCSN analyzes and archives a huge quantity of data every year, including catalog listings (time, magnitude, location, and location quality), phase data (arrival times, qualities and first motions at each station) and seismograms (Fig. 6). The data from the SCSN are recorded and processed using the CUSP (Caltech/USGS Seismic Processing) system (Johnson, 1983) on a network of VAX/VMS computers. The data are maintained in CUSP binary data bases, accessible through a series of programs.

We distribute these data to researchers and other users primarily through the SCEC_DC, which is accessible via Internet. These data are used by a wide variety of people—researchers from the U.S. Geological Survey, Caltech and other academic institutions, geotechnical consultants, insurers,

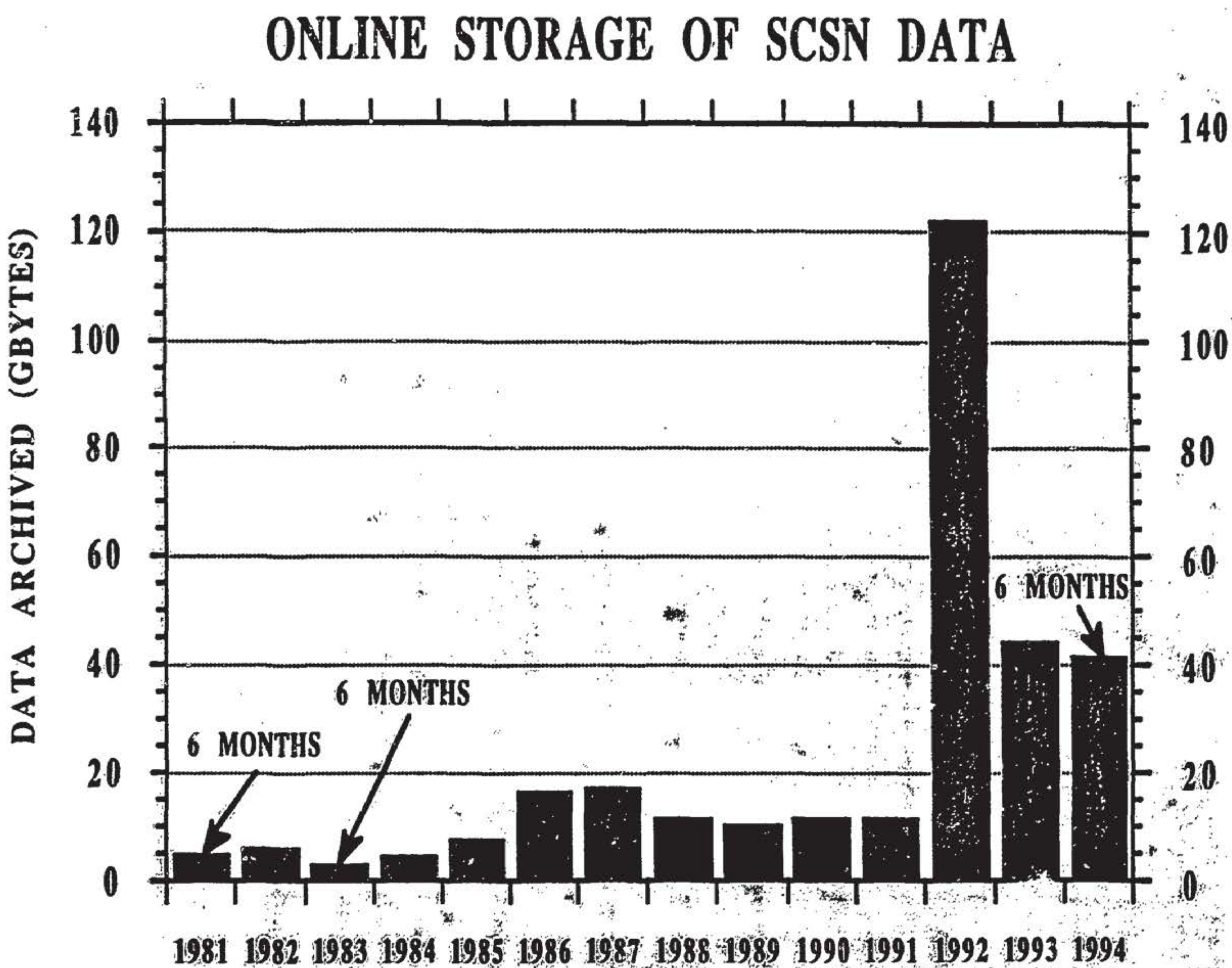


Fig. 6. Histogram showing quantity of seismic data acquired and stored by SCSN per year.

lawyers, and the general public. In Fig. 7 we show schematically how the data reach the various user communities. The three sources of data, SCSN, TERRAscope, and portable instrument data, are shown to the left, the means of distribution are shown in the middle, and the types and numbers of users are shown to the right. This flow chart clearly shows that Internet is the preferred way of obtaining earthquake data.

Earthquake Catalog. The earthquake catalog is the most commonly used of the SCSN data bases. It is complete for events $M \geq 3.0$ since 1932 and includes over 200,000 events. It provides a unique resource in seismology because it is the only U.S. catalog in which magnitudes of earthquakes above 3.0 have been determined in the same way for a period this long. To increase the usefulness of the catalog, the staff of the SCSN prepares weekly and quarterly digests of the recorded seismicity. A listing of all earthquakes above 2.5 is prepared quarterly and mailed to 185 recipients, many in industry. This listing and a plot of the events is also available through the World Wide Web on Internet.

Phase Data. The phase data, arrival times and first motions at all timed stations, are more voluminous than the catalog with about 300–500 megabytes of data now created per year. The phase data from 1932 to present are now available in digital format. Two large data gaps exist in this time period for which the digital seismograms have not yet been processed: May 1980–Feb. 1981 and Mar.–June 1983. A subset of the stations were timed off of paper records for earthquakes $M \geq 2.5$ in these time periods and these data are available. A small data gap exists for the 1992 Landers sequence where about 10,000 earthquakes still need to be timed (Fig. 8).

Processing of Northridge aftershocks is complete from February 7 to the present. During the early weeks of the earthquake sequence all events recorded between January 17 and February 7 were preliminarily located. Seismic analysts are now resuming processing of those early events and have completed the processing for approximately 75% of the 4300 events recorded during that time period (Fig. 8). This data is available through the SCEC_DC as processing is completed.

Seismogram Data Base. All the seismic signals, except for the Wood-Anderson instruments, have been digitized and recorded on computer since 1977. Because of their size (an *average* of 10–20 megabytes of data per earthquake), seismograms are stored on a dedicated optical platter on the SCEC mass storage jukebox and a backup copy is put on DAT tape within 1 or 2 days of being recorded. All of the digital seismograms have been copied to the SCEC_DC mass-store system.

SCEC_DC

The Data Center of the Southern California Earthquake Center (SCEC_DC) that is funded by the SCEC has greatly increased the use of the data from SCSN for scientific research (Fig. 9). The SCEC_DC is located at Caltech and the staff of both the SCSN and SCEC_DC work together to maintain high data quality and to ensure rapid distribution of data. The mass-store system, which became operational on 1 October 1991, and a 2nd system added in March 1994, provides on-line storage for more than 600 Gbytes of data. The availability of 60 years of catalog, 30 years of phase

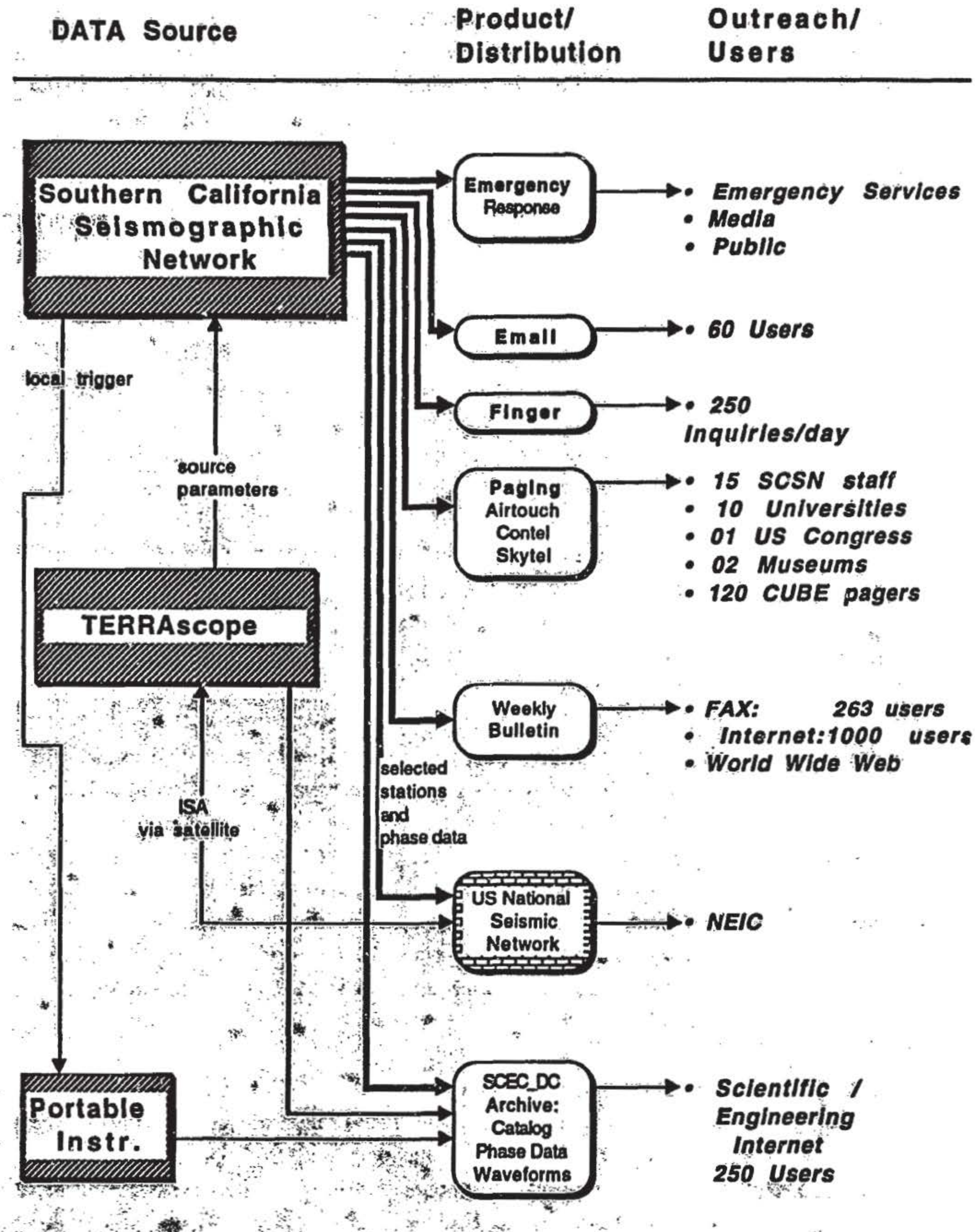
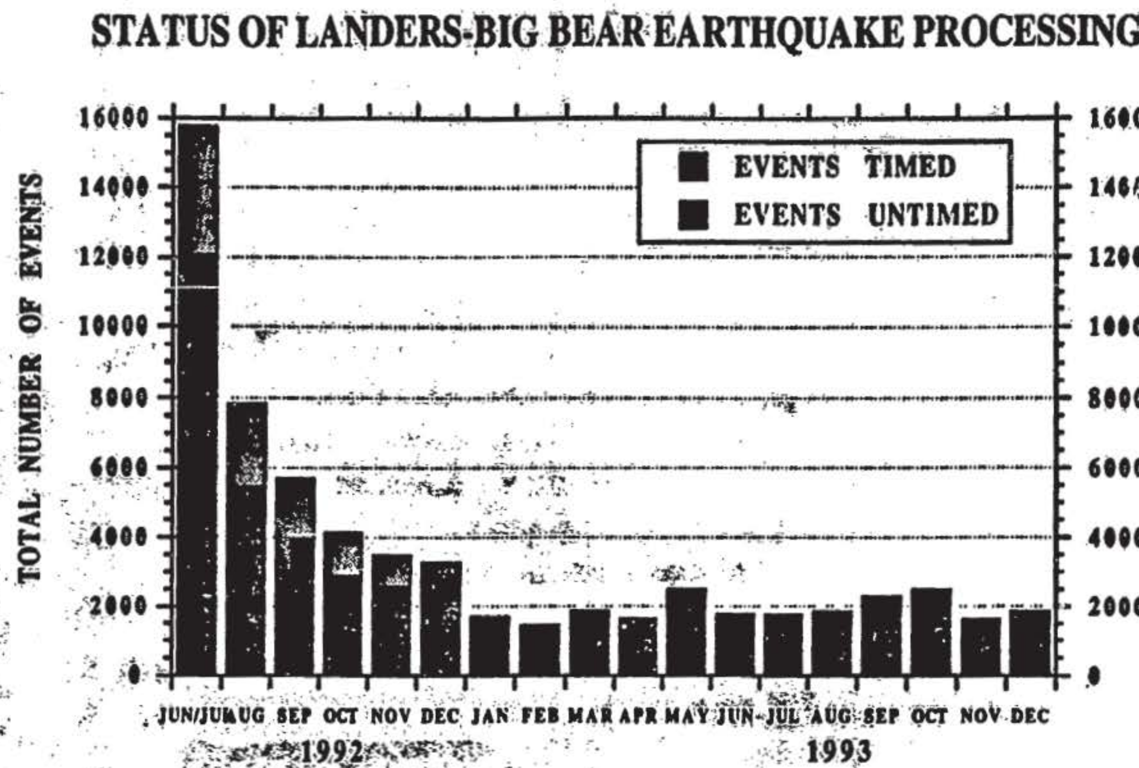


Fig. 7: Flow of information from SCSN and TERRAscope to the users.



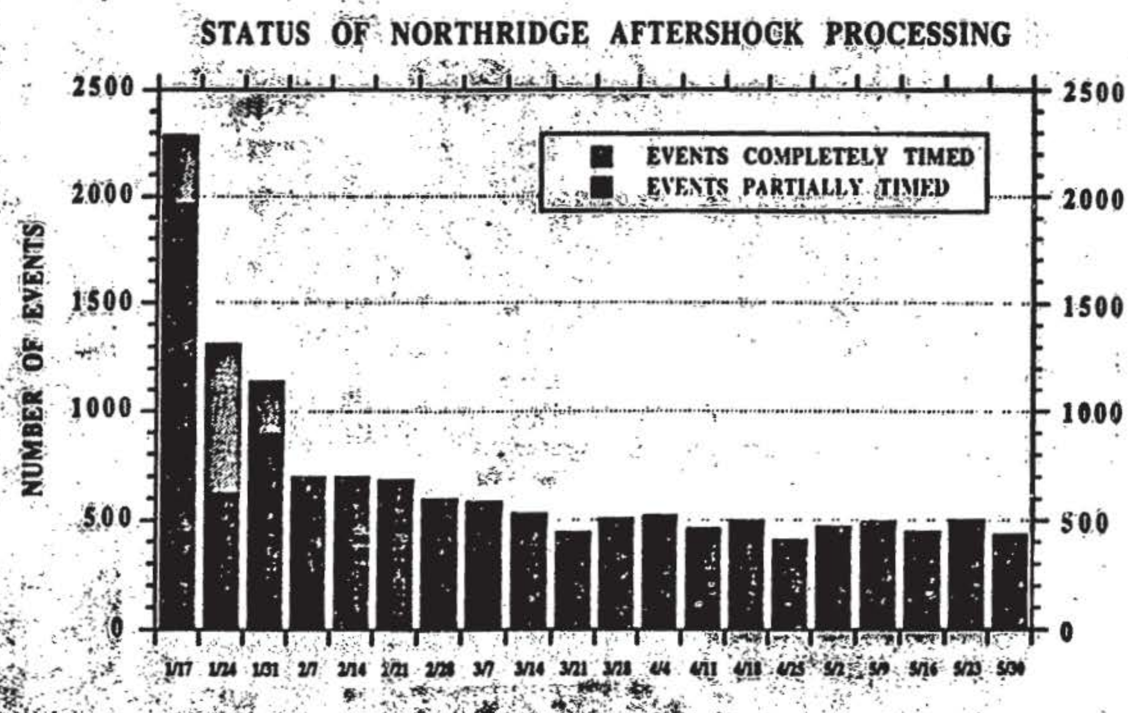


Fig. 8. Status of the 1992 Landers and 1994 Northridge data processing.

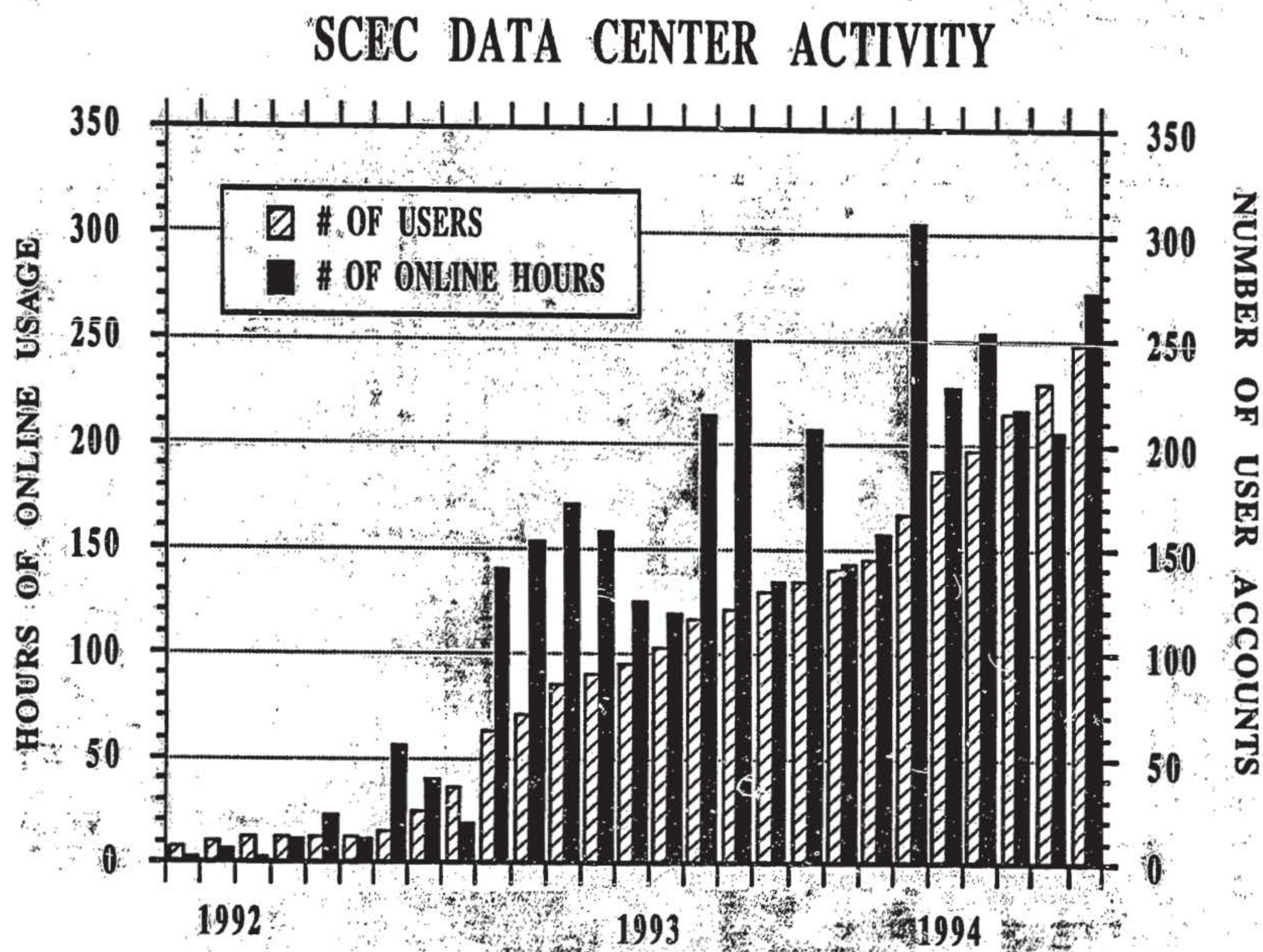


Fig. 9. User activity at the SCEC_DC.

54

data, and 14 years of digital seismograms on both Unix and VMS computers and on line over Internet/NSFNET greatly improves the access to the data.

The SCEC Data Center (SCEC_DC) has been expanding continually since it came on line approximately 2½ years ago. Access to the SCEC_DC is still primarily through individual user accounts (currently totaling 221), at a rate of approximately 200 hours/month (Fig. 9). In addition, a "bulletin board" system was implemented in April 1994, which allows researchers to request accounts, and obtain information regarding data stored on the SCEC_DC, as well as the availability and access to GPS and Strong Motion Data. We expect to expand the capabilities of this bulletin board system to include such things as anonymous ftp of weekly earthquake reports, as well as conducting routine earthquake catalog searches.

The SCEC_DC activity in 1994 is primarily focused on adding a second mass storage device to our existing system. This addition, which included an upgrade of the operation system, as well as the archival data management software, was completed on March 23, 1994. The new configuration appears to users exactly the same as the previous one-Jukebox configuration, i.e., as a single Unix filesystem. The SCEC_DC's on-line storage capacity is now 600 Gbytes.

Currently the SCEC_DC archive consists of 347 Gbytes of seismic and geodetic data. Approximately 60 Gbytes of this data is made up of raw SCSN data recorded during the Joshua-Tree-Landers Earthquake sequence, as well as all data archived directly by the SCSN on to the Jukebox since the Northridge earthquake of this year. GPS data from UCLA, in RINEX as well as raw data formats, currently occupies approximately 700 mb of storage space. Approximately 80% of the processed SCSN data has been backed up onto 5-Gbyte exabyte tapes since January of this year. A copy of these backup tapes will be stored at the Northern California Data Center.

The SCEC_DC has recently implemented a relational database, in which the indexes into the database are the event ID's associated with individual earthquakes. A description of this database, as well as other features of the SCEC_DC, was presented at the April 1994 meeting of the SSA in Pasadena. A binary version of the database was developed from ASCII files which store earthquake and seismogram attributes, as well as indices into the waveform archives. The format of these ASCII files is identical to the system used at the Northern California Data Center. The ASCII format is also the means by which portable and TERRAscope data are entered into the database. The binary version of the database is accessible through a sort program and a subroutine library. Hierarchical event and phase catalogs are derived from the binary database (Fig. 10). User-created catalogs (e.g., relocated Landers' aftershocks) can be connected to this system through the use of a relational key (the "eventid"). In the next few months we plan to merge TERRAscope and portable data into the binary database. UCSD has already created ASCII files in the SCEC_DC format for portable data recorded during the 1992 Landers-Big Bear earthquake sequence.

To access SCEC_DC do the following: *rlogin scec.gps.caltech.edu -l bulletin*

DATA FLOW

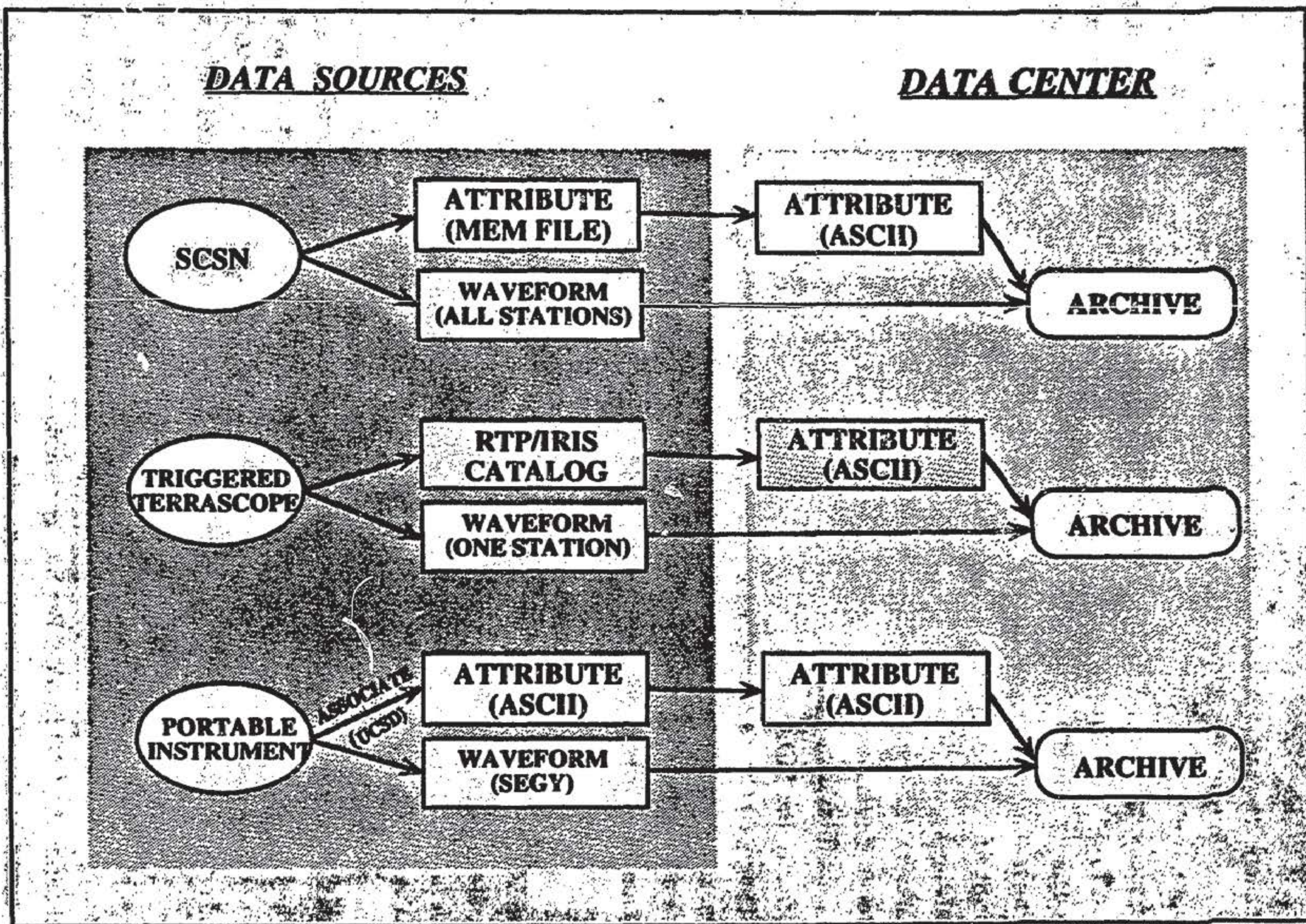


Fig. 10. Schematic data flow for the SCEC_DC.

Caltech/USGS Broadcast of Earthquakes (CUBE)

The CUBE project is an outreach program under Caltech's Earthquake Research Affiliates program. This is a cooperative research project between Caltech, USGS, and several transportation and utility companies to develop a sophisticated real-time seismic information system using data from SCSN and TERRAscope. The CUBE project has 17 contributing members and 10 non-contributing members. The objectives of the CUBE project are 1) develop the capability to provide near-real-time earthquake information to critical users such as utilities and transportation companies, 2) develop user software for remote evaluation of the earthquake information, and 3) educate the members about earthquakes and the most recent research results. The participants in this project are actively involved in the research using a radio pager-computer display system. The feedback from these participants helps Caltech and USGS seismologists to improve the system, thus contributing to seismic hazard reduction and promoting the advancement of seismology.

The CUBE project is for advanced technical users who need the two-way communication to Caltech/USGS Pasadena to ensure receiving reliable earthquake information to save lives and protect property. Many of these CUBE members may establish dedicated communications links, in addition to the pagers, to Caltech/USGS Pasadena to ensure reliable delivery of information. As part of CUBE, we also plan to establish future cooperative efforts that will consist of sharing real-time strong motion data from instruments operated, for instance, by utility companies.

Future Plans: SCSN for the Year 2000

It is our goal for the year 2000 to evolve the SCSN into a modern reliable earthquake monitoring network capable of providing real-time information and on-scale high fidelity ground motion data. This ambitious goal has in part evolved from our experience with the 1992 M_w 7.3 Landers and the M_w 6.7 Northridge earthquakes. As the local governments, the private sector, and the public become more aware of the earthquake problem there is an increased need for accurate information. If reliable real-time earthquake information is available, it can be used by many segments of society to protect life and property. Similarly, there is a dual need for rapid, accurate evaluation of strong ground shaking. First, maps of strong ground shaking are needed to guide emergency operations immediately following a major earthquake. Second, strong ground shaking that in most cases causes over 95% of the earthquake damage needs to be mapped to facilitate our understanding of damage and subsequent improvements of building codes.

New Digital Instrumentation

At present the near-real-time earthquake information that is provided by SCSN is not considered to be reliable because the instrumentation is inferior and the data are often contaminated by electrical noise. New instrumentation for SCSN needs to have minimal electrical noise and to be able to record both weak and strong ground motion onscale at a reasonable cost.

Caltech has a pilot project funded by the Department of Commerce of the State of California to develop a near-real-time reporting strong ground motion network. This project is in cooperation with Kinemetrics Inc. in Pasadena. The objectives are to have Kinemetrics develop a prototype digital strong motion instrument (K2) that can both provide real-time time-series data as well as processing of data on site. Caltech is developing some of the software for the new instrument. As part of this project, four instruments will be deployed in 1994 at remote sites in the Los Angeles area. These instruments will be connected via dedicated Frame-Relay to Caltech in Pasadena. Caltech will develop data analysis tools intended to provide near-real-time ground motion maps from these and other available sites, such as TERRAscope. This project is a pilot project that will influence the future modernization of instrumentation at remote sites in the SCSN.

The future upgrade of SCSN may include six-component sensors with three-component FBA and three-component high-gain velocity sensor at each site.

Digital Data Transmission

At present much of the SCSN analog data are transmitted on dedicated leased analog phone lines, dedicated microwave circuits, and radio links. This mode of transmitting data is not particularly reliable and leads to common electronic noise bursts and several single points of failure. To move our data communications from analog to digital we have sought advice from the local phone companies such as Pacific Bell and GTE.

We have received a grant from the California Research Network (CalREN), a non-profit foundation funded by Pacific Bell. This grant will provide $80K worth of Frame-Relay telecommunication cost for TERRAscope and any USGS or other digital seismographic stations in southern California. The time duration of this grant is from September 1994 to June 1996. Frame-Relay works like a dedicated computer network where virtual dedicated circuits are defined in software by the phone company. Pacific Bell estimates that the usage of the Frame-Relay system will drop following a major earthquake because many businesses that routinely use the Frame-Relay system may be temporarily shut down, due to the earthquake.

This grant will make it possible to receive real-time digital data at a rate of 56K bits/sec from 20 remote stations to Caltech in Pasadena. It will also make it possible to test modern communications methods for seismology. The Frame-Relay service has only installation and monthly fee charges; it has no distance or usage charges. We are hopeful that the Frame-Relay technology may be scaled up easily to a network of 1000 remote stations.

Initially we plan to connect our remote sites via RS-232 ports defined in software on the Frame-Relay. Further development will include connecting remote stations to Caltech using TCP/IP protocol and operating the seismic network as a Local Area Computer Network (LAN).

Real-time Earthquake Notification

The societal need for near-real-time earthquake information is great. First, there is a need to know about small earthquakes that are felt and to confirm that they are indeed small and no emergency response is required (R. Andrews of OES, personal communication, 1994). In general our near-real-time notification system is very good at handling these types of events (Fig. 11a).

Rapid determination of earthquake source parameters after large earthquakes is very important for earthquake hazard mitigation. After a damaging earthquake, the emergency operations made in the first hours can be crucial for saving lives and protecting properties. These operations need to be based on the characteristics of the earthquake that has just occurred. The location, depth, size, mechanism, and rupture direction all directly affect the extent and distribution of damage. If the earthquake source parameters can be quickly and accurately determined after a large earthquake, they can be used effectively, in conjunction with the information of the site and macro seismic data, to determine the resulting ground shaking pattern. We have tried aggressively to provide information about major earthquakes rapidly during the last 3 years. We have had one success and several failures.

Our early success was the notification of the occurrence of the M_w 5.8 1991 Sierra Madre earthquake and subsequent stopping of Santa Fe railroad trains in the Pasadena area. One of our most spectacular failures occurred during the M_w 6.7 Northridge earthquake, when our real-time software (ISAIAH) failed to provide a location and hence we had no information available for more than 20 minutes. At present we have focused our efforts toward fixing software and hardware problems that are known to contribute to the failure of our near-real-time notification system.

ISAIAH: The SCSN real-time notification system is based on a real-time software system, Information About Earthquake Activity in a Hurry (ISAIAH), developed by the USGS in Pasadena, that analyzes data from all 343 channels and provides first estimates of preliminary locations and magnitudes within 30–40 seconds (Fig. 11b). ISAIAH replaced the old 64-channel RTP developed by the USGS in Menlo Park.

This automated software gives fast reliable locations and preliminary magnitudes for events within the network and is used to send magnitude and location information to E-mail, Finger, and pagers carried by USGS, Caltech personnel, and CUBE members. Preliminary magnitudes for smaller events ($M < 4$) are estimated from amplitudes in a window following the S wave (Fig. 11a). Updated magnitudes are estimated from an on-line program which automatically calculates Wood-Anderson response seismograms from the low-gain seismometer and FBA data channels. Amplitudes from these simulated Wood-Andersons are used with the RTP location to get a local magnitude (M_L). For large earthquakes ($M > 4$) we determine a magnitude from TERRAscope data, which is available within 4 minutes of the occurrence of the event.

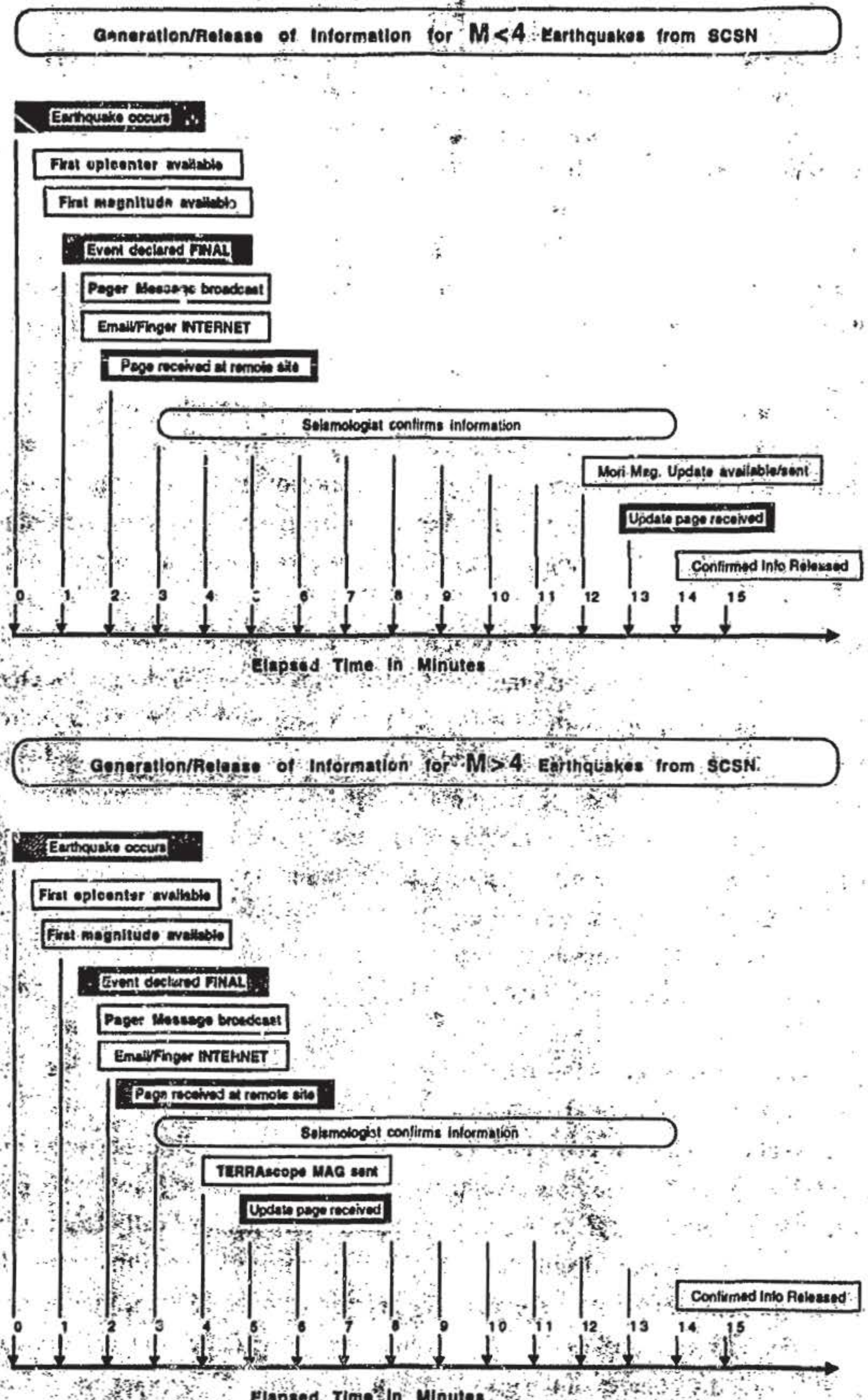


Fig. 11. The sequence of tasks that take place as a small (M < 4) or a large (M > 4) earthquake is located and magnitude is determined by SCSN and TERRAscope automatically.